MULTI-MODAL FORCED VORTEX DEVICE

[0001] This application is related to U.S. provisional patent application, entitled "Unmanned, Sea, Land, Air, Vehicle, (U.S.L.A.V.): an All Terrain Unmanned, Submersible, Wall Climbing, Flying Vehicle" (serial no. 60/431,776), filed 9 December **200**2.

Background

[0002] The invention relates to the area of forced vortex technology. More specifically, but not by way of limitation, the invention is directed to a multi-modal forced vortex device that can generate variable magnitude (1) attractive forces, (2) down or pushing forces, (3) up or lifting forces, and (4) yaw, pitch and roll forces.

[0003] In recent years there have been substantial advancements in understanding the physics of forced vortex technology. Generally, when a set of partially enclosed blades is made to rotate, the rotating blades create a positive or negative pressure inside the partially enclosed volume (relative to the environment outside the partially enclosed volume) depending upon the speed and direction of the rotating blades and the amount and direction of fluid (*e.g.*, air or water) flowing through the enclosed volume. When the pressure within the partially enclosed volume is negative relative to the ambient pressure, surrounding fluid rushes into the lower pressure area around the blades creating a down-force on the device housing the rotating blades. Alternatively, when the pressure within the partially enclosed volume is

positive relative to the ambient pressure, an up-force is created on the device housing the rotating blades.

[0004] Currently, the lift and down-force modes of operation are used across a wide range of fields. For example, airplanes, helicopters and submarines produce propulsive forces based on these principles. In addition, domestic ceiling fans are adjustable to either push down air near the ceiling or lift the air nearer to the ground towards the ceiling. Similarly, variable pitched water-jet propulsors provide forward or reverse motion to ships and submarines. The forced vortex attractive force mode of operation created by this technology has also been used to increase the traction of vehicles on slippery and vertical surfaces and for use as a material handling device.

[0005] However, there are still many problems in the area of forced vortex technology. The rotating blades currently used in the forced vortex technology field are often unenclosed or mounted at a fixed angle of attack, thereby greatly limiting their ability to generate more than one type of force (*e.g.*, a downward/pushing force or an upward/lifting force or an attractive/suction force). Other devices have blades mounted directly onto a disk, creating a heavier set of blades that require greater amounts of energy to operate/rotate for a given amount of generated force. Still other devices have a disk partially enclosing the blades which is mounted directly onto a rotating axis. Each of these forced vortex devices are limited to a single mode of operation. Additionally, each forced vortex device is designed to function in a single set of environmental conditions. In addition to these operating limitations, existing forced vortex technologies create safety concerns. For example, blades that become disconnected during operation

and which are not enclosed or only partially enclosed create a severe safety risk and can easily cause injury or death.

[0006] Thus, it would be beneficial to provide a forced vortex apparatus capable of operating in a number of different modes. It would be a further benefit to provide these capabilities in a device that is inherently safer to operate than existing forced vortex devices.

Summary

[0007] In one embodiment, the invention provides a multi-modal forced vortex device comprising a top plate having adjustable fluid passages, a side wall coupled to the top plate to create a partially enclosed volume, a plurality of blades adapted to rotate within the partially enclosed volume, pitch adjustment mechanisms to adjust the pitch of at least one of the blades and a rotating means for rotating the plurality of blades. During operation, a multi-modal forced vortex device in accordance with the invention may be operated in any one of five different modes, depending upon the configuration of its fluid apertures, blade pitch and blade rotational speed and/or direction. In a first (forced vortex) mode, the adjustable fluid apertures are closed and the rotating blades are pitched and rotated to generate an attractive force that pulls the device towards and/or against the surface of any object below it. In a second (down or pushing force) mode, the adjustable fluid apertures are partially or fully opened and the rotating blades are pitched and rotated to generate a downward or pushing force on the device. In a third (up or lifting force) mode, the adjustable fluid apertures are

partially or fully opened and the rotating blades are pitched and rotated to generate an upward or lifting force on the device. In a fourth (yaw, pitch and roll) mode, the adjustable fluid apertures are partially or fully opened and the rotating blades are pitched (in unison, counter-unison or independently and/or continuously) away from 0º/90º (relative to their direction of rotation) to generate yaw and/or pitch and/or roll forces on the device. In a fifth (standby) mode, the adjustable fluid apertures may be partially or fully opened or fully closed, and the rotating blades are pitched such that substantially no upward, downward, side or vortex forces are imparted to the device. Alternatively, blade rotation may be stopped to effect the fifth mode.

Brief Description of the Drawings

[0008] A better understanding of the invention can be had when the following detailed description of the preferred embodiments is considered in conjunction with the following drawings, in which:

[0009] Figure 1 shows a side view of a multi-modal forced vortex device in accordance with one embodiment of the invention.

[0010] Figure 2 shows a top view of a multi-modal forced vortex device in accordance with one embodiment of the invention.

[0011] Figure 3 shows a variable diameter iris mechanism in accordance with one embodiment of the invention.

[0012] Figure 4 shows a bottom view of a multi-modal forced vortex device in accordance with one embodiment of the invention.

[0013] Figures 5A, 5B, 5C and 5D illustrate four examples of an independently adjustable blade for use in a multi-modal forced vortex device.

[0014] Figure 6 shows a top view of a multi-modal forced vortex device in accordance with another embodiment of the invention.

[0015] Figure 7 shows an underside view of a multi-modal forced vortex device in accordance with FIG. 1 and having a mesh cover.

[0016] Figure 8 is a block diagram of a multi-modal forced vortex device in accordance with yet another embodiment of the invention.

[0017] Figure 9 shows, in block diagram form, a vehicle using a multi-modal forced vortex device in accordance with one embodiment of the invention.

Detailed Description

[0018] A multi-modal forced vortex device is described. The following embodiments of the invention are designed to generate variable magnitude: attractive forces in a first mode; down or pushing forces in a second mode; up or lifting forces in a third mode; yaw, pitch and roll forces in a fourth mode; and no appreciable forces in a fifth, or standby mode. While described herein as a unitary device, those of ordinary skill in the art will recognize a multi-modal forced vortex device in accordance with the invention can be coupled to a rigid body during use (*e.g.*, a land, sea or aerial vehicle). Accordingly, the embodiments described herein are illustrative only and are not to be considered limiting in any respect.

[0019] Referring to FIG. 1, multi-modal forced vortex device **100** in accordance with one embodiment of the invention comprises top plate **105** and side wall **110** that jointly create a partially enclosed volume, skirt **115** to provide an interface between device **100** and the surrounding environment and power plant **120** to provide the energy to rotate shaft **125** and variable-pitch blades attached thereto (represented in outline as **130**).

[0020] In one embodiment, top plate **105** and side wall **110** may be constructed of metal that are welded, bolted or clamped together. In another embodiment, top plate **105** and side wall **110** may be constructed of a plastic or composite material that are glued together. In yet another embodiment, top plate **105** may be constructed from a first material and side wall **110** from a different material. One of ordinary skill in the art will recognize that the type of material used to construct a multi-modal forced vortex device in accordance with the invention depends upon the use and/or environment in which it is to operate. For example, device **100** is to be operated in air, blade speeds needed to generate a desired force may be greater than for a similar sized device designed to operate in a more viscous fluid such as water. Accordingly, the strength of the enclosure (top plate, side wall) as well as the material with which the blades are constructed and how they are coupled or fastened to shaft **125**, may be entirely different. It will be recognized by those of ordinary skill in the art that the higher or wider side wall **110**, the larger the partially enclosed volume created by the combination of top plate **105** and side wall **110**. In general, the greater the amount of fluid passing across the blades (that is, through the partially enclosed volume created

by top plate **105** and side wall **110**), the greater the forced vortex capable of being generated. Additionally, the height of the side wall must accommodate the variation in pitch of rotating blades **130** as they are adjusted for the most efficient angle of attack in a given set of conditions (see discussion below). It is further noted that while the embodiment of FIG. 1 depicts side wall **110** as being substantially perpendicular to top plate **105**, the present invention also contemplates coupling side wall **110** at different angles. For example, side wall **110** may be fixed at angles greater or less than ninety degrees to change the volume of fluid inside the partial enclosure created by top plate **105** and side wall **110**.

[0021] Coupled to side wall **110** and extending downward therefrom, skirt **115** provides a relatively flexible protective ring. One function of skirt **115** is to provide a relatively pliant interface between device **100** and the environment. For example, when operated in a mode to create a down or forced vortex force, skirt **115** may provide a coupling interface to an object. Commensurate with its function, skirt **115** may be embodied in any suitable material such as, for example, plastic or rubber. In addition, skirt **115** may be coupled to side wall **110** using any suitable means such as glue, bolts or a retainer ring. As with the coupling between top plate **105** and side wall **110**, the present invention contemplates a smooth fusion between side wall **110** and skirt **115** to reduce the errant eddies and currents associated with turbulent fluid flow between device **100** and its environment. It is noted that while the illustrated embodiment shows skirt **115** to be relatively wide (compared to the height of side wall **110**), this is

not necessary. Further, depending upon the environment, skirt **115** may not be present in some embodiments of the invention.

[0022] In some embodiments, a porous mesh may be coupled across the bottom of device **100** (*i.e.*, near rotating blades **130**) to prevent the uptake of foreign objects into the partially enclosed volume (not shown in FIG. 1). Referring to FIG. 7, for example, porous mesh **700** is shown coupled to the bottom of device **100** (see FIG. 1). If such a mesh is used, it is preferable that it present negligible effect on flow of fluid into and/or away from rotating blades **130**. It is further preferable that this mesh be constructed from concentric rings made of metal, plastic or a composite. In another embodiment, the mesh may be mechanically adjustable in the form of an iris so that the degree to which rotating blades **130** are shielded may be varied. As with the coupling between top plate **105** and side wall **110**, the present invention contemplates a smooth fusion between side wall **110** or skirt **115** and the protective mesh to reduce the errant eddies and currents associated with turbulent fluid flow between device **100** and its environment.

[0023] In the embodiment shown in FIG. 1, top plate **105** includes apertures **135**, **140**, **145**, **150** and **155** which can be "opened" to permit, or "closed" to restrict, fluid flow into or out of the partially enclosed volume created by top plate **105** and side wall **110**. Various embodiments of the invention may include more or fewer apertures and may further utilize aperture geometries other than the fixed circular shape illustrated -- in some embodiments top plate apertures may have a tapered shape such as an ellipsoid or triangle. In other embodiments, substantially all of top plate **105** not

used to provide structural support to side wall **110** and power plant **120**, forms a variable diameter iris that can be gradually opened and closed to regulate the amount of restriction presented to fluid moving into and out of the partially enclosed volume created by top plate **105** and side wall **110**.

[0024] With respect to apertures **135**-**155**, in one embodiment top plate **105** is functionally coupled to a lower plate that also has apertures in it. When top plate **105** is moved relative to this lower plate, the apertures between the two may be fully aligned (to permit maximum fluid flow into and out of the partially enclosed volume), fully occluded (to maximally restrict fluid flow into and out of the partially enclosed volume) or partially occluded. Referring now to FIG. 2, top plate **105** is shown over lower plate **200** which has apertures **205**, **210**, **215**, **220** and **225** corresponding to top plate apertures **135**-**155**. In this embodiment, geared shafts **230** and **235** penetrate top plate **105** (and are powered by power plant **120** or a separate power source) and engage gear teeth section **240** and **245** located on the outer circumference of lower plate **200**. As geared shafts **230** and **235** are rotated, lower plate **200** is moved relative to top plate **105**. In the embodiment shown, geared shafts **230** and **235** may be rotated clockwise and counter-clockwise to align or occlude lower plate apertures **205**-**225** with top plate apertures **135**-**155**. In another embodiment, the entire circumference of lower plate **205** may comprise gear teeth. A benefit of this approach is that gear shafts **230** and **235** only need be rotated in a single direction. As noted above, the power source to drive (or rotate) gear shafts **230** and **235** may be the same power plant as that used to rotate the enclosed blades (see discussion

below), or it may be a separate power source. Also as noted above, the number and shape of apertures may vary. Referring to FIG. 6, for example, there is shown non-circular apertures **600** that result from the above-described case where top plate apertures (*e.g.*, aperture **135**) do not fully overlap or coincide with lower plate apertures (*e.g.*, aperture **205**). In addition, the number and shape of lower plate apertures do not have to match or equal the number or shape of top plate apertures.

[0025] Referring to FIG. 3, in another embodiment apertures **135**-**155** and lower plate **200** may be replaced by a variable diameter iris mechanism having a flexible toughened rubber circular iris **300** coupled to side wall **110** using multiple studs or bolds **305**. Iris cable bolts **310** attach iris cables **315** to iris **300**. At the other end of each iris cable **315** are iris cable actuators **320** which reel iris cables **315** in and out to vary the open aperture of iris **300**, thereby varying the restriction presented to fluid flow moving into, or out of, the partially enclosed volume housing blades **130**. Beams **325** provide structural support for iris **300**.

[0026] As illustrated in FIG. 1, power plant **120** comprises shaft **125** which tends downward into the partially enclosed volume created by top plate **105** and side wall **110**. One function of power plant **120** is to rotate shaft **125** which, in turn, rotates a plurality of variable pitch blades attached thereto within the partially enclosed volume created by top plate **105** and side wall **110**. The form of power plant **120** is a design choice of the implementer. For example, power plant **120** may be an internal combustion engine, an electric motor (*e.g.*, a "pancake" motor), a turbine engine (*e.g.*, a gas turbine) or a fuel cell. In other embodiments, power plant **120** may be the power

plant of a device to which device **100** is coupled. Referring to FIG. 9, for example, if multi-modal forced vortex device **100** is coupled to vehicle **900**, power plant **120** may be the vehicle's engine. In this embodiment, shaft **125** may include universal joints and/or other mechanical means to transfer power from the engine to the blades (see discussion below).

[0027] Figure 4 shows a bottom view of multi-modal forced vortex device **100** (*i.e.*, looking directly into the partially enclosed volume created by top plate **105** and side wall **110**). As shown in this embodiment, blades **130** (see FIG. 1) comprise four separate blades **405**, **410**, **415** and **420**, each of which are coupled to shaft **125** through pitch control units **425**¸ **430**, **435** and **440** respectively. In one embodiment, pitch control units **425**-**440** permit blade rotation from between approximately zero degrees (0º) and approximately ninety degrees (90º). In another embodiment, pitch control units **425**-**440** permit blade rotation between approximately zero degrees (0º) and approximately one hundred eighty degrees (180º). In yet another embodiment, pitch control units **425**-**440** permit blade rotation of approximately three hundred sixty degrees (360º). In addition, pitch control units **425**-**440** may be adapted to control their blades in unison (multiple blades moved or pitched in the same direction and degree – also known as "collective pitch control" in the fields of helicopter and waterjet propulsor design), in counter-unison (multiple blades moved or pitched in opposite directions and degree) or independently (each blade may be pitched independent of other blades). Pitch control units **425**-**440** may be also be adapted to continuously vary the pitch of each blade as it rotates. This latter embodiment will be recognized as

"cyclic pitch control" as used in many current helicopter rotor designs. Pitch control devices in accordance with the invention may be of any type suitable to adjust the pitch of a rotating blade. One of ordinary skill in the art will recognize that the precise type of control element can depend upon, *inter alia*, the weight, rotational speed and expected generated forces device **100** is designed to produce. In general, then, pitch control devices include swash plates, hydraulic or pneumatic actuators, electric motors, electromagnets and the like.

[0028] Referring to FIG. 5A, blade **405** is shown in a "full pitch" or 90° pitch position. In this configuration, blade **405** sweeps out its maximum volume as it rotates about shaft **125**. Referring now to FIG. 5B, blade **405** is shown in a "no pitch" or 0° pitch position. In this configuration, blade **405** sweeps out its minimum volume as it rotates about shaft **125**. In another embodiment, blades **405**-**425** are pitched relative to their "top" edge as illustrated in FIG. 5C. In this embodiment, blade **405**'s top edge is continuously maintained in a close spatial relationship to the bottom of top plate **110** (or lower plate **200**). Blade **405** in FIG. 5C is shown in its no-pitch position. As shown in FIGS. 4 and 5, the tips of blades **405**, **410**, **415** and **420** sweep as close to side wall **110** as reasonable when in either the full or no pitch positions. Similarly, it is significant (although not required) that blades **405**, **410**, **415** and **420** sweep as close to top plate **105** as reasonable when in the no full position and, in the embodiment of FIG. 5C, when in the full pitch or no pitch positions.

[0029] A multi-modal forced vortex device in accordance with the invention contemplates using various shaped blades. In one embodiment, for example, each

blade has an aerofoil cross-section and is rectangular in overall shape. In another embodiment, the blades may be tapered at one or both ends. In still another embodiment, the blades may be oval in shape.

[0030] In operation, multi-modal forced vortex device **100** may be operated in any one of five different modes, depending upon the configuration of its fluid apertures, blade pitch, rotational speed and, possibly, rotational direction. In a first (forced vortex) mode, apertures **135**-**155** are closed and rotating blades **405**-**420** are not in the no pitch position so that an attractive force is created by the generated forced vortex that pulls device **100** towards and/or against the surface of any object below it. It will be recognized that, for a given blade size, the magnitude of the generated attractive force in this mode depends upon the blades' rotational speed and the degree to which the blades are pitched – with maximum force generated in the full pitch position. In a second (down or pushing force) mode, apertures **135**-**155** are partially or fully opened and rotating blades **405**-**420** are pitched to a negative angle of attack (relative to their direction of rotation) so that a downward or pushing force is created on device **100**. In a third (up or lifting force) mode, apertures **135**-**155** are partially or fully opened and rotating blades **405**-**420** are pitched to a positive angle of attack (relative to their direction of rotation) so that an upward or lifting force is created on device **100**. In a fourth (yaw, pitch and roll) mode, apertures **135**-**155** are partially or fully opened and the rotating blades **405**-**420** are pitched (in unison, counter-unison or independently and/or continuously) away from 0º/90º (relative to their direction of rotation) to generate yaw and/or pitch and/or roll forces on device **100**. In a fifth (standby) mode,

apertures **135**-**155** may be partially or fully opened or fully closed, and rotating blades **405**-**420** are pitched at 0º so that substantially no upward, downward, side or vortex forces are imparted to device **100**. Alternatively, blade rotation may be stopped to effect the fifth mode. (If blade rotation is stopped, blade pitch angle is irrelevant.) In those embodiments utilizing pitch control units capable of pitching blades between approximately 0º and **360**º, device **100** may be transitioned between modes 1 and 3 or 2 and 3 without the need to change the blades' rotational direction. In those embodiments utilizing pitch control units capable of pitching blades between approximately 0º and 90º, device **100** may be transitioned between modes 1 and 3 or 2 and 3 by reversing the blades direction of rotation.

[0031] By way of example only, one embodiment of multi-modal forced vortex device **100** uses a circular top plate having a 0.5 meter diameter, a side wall of approximately 3 cm, a skirt of approximately 1 cm, eight (8) blades, each of which are rectangular in shape (25 cm × 3 cm × 8 mm) with an aerofoil cross-section, a 2 kilowatt electric motor power plant capable of rotating the blades at a maximum of 5,000 rpm (in air), and eight independent electromagnetic pitch control units to provide 360º pitch control. In this embodiment, the top plate, side wall and blades are constructed of a carbon fibre composite and the skirt is a neoprene rubber. In this configuration, device **100** has a mass of approximately 20 Kg, but can generate an attractive force (mode 1) of approximately 1,000 Newtons, pushing (mode 2) and lifting (mode 3) forces of approximately 2,000 Newtons and yaw, pitch and roll (mode 4) forces of approximately 1,500 Newtons.

[0032] Various changes in the materials and structure of the illustrated embodiments are possible without departing from the scope of the claims. For instance, the number of blades is not restricted to the four-blade embodiments described herein. It is contemplated that, depending upon the physical size of device **100** (which can vary from millimeters to several meters in diameter), anywhere from 2 to 72 blades (rotating up to approximately 40,000 rpm) may be used. It is further noted that while the illustrated embodiments utilize fluid apertures having a circular cross section, this is not necessary. Nor is it necessary that the top plate have a circular cross-section. It will also be recognized that numerous devices may be connected together in any number of configurations, separated by varying horizontal and vertical distances from one another. See, for example, vortex device **800** in FIG. 8. For example, two multi-modal forced vortex devices in accordance with the invention may be mounted back-to-back to form a contra-rotating assembly. One benefit of this embodiment is that one of the two devices act as an anti-torque device to the other device. Thus, while the invention has been disclosed with respect to a limited number of embodiments, numerous modifications and variations will be appreciated by those skilled in the art. It is intended, therefore, that the following claims cover all such modifications and variations that may fall within the true spirit and scope of the invention.